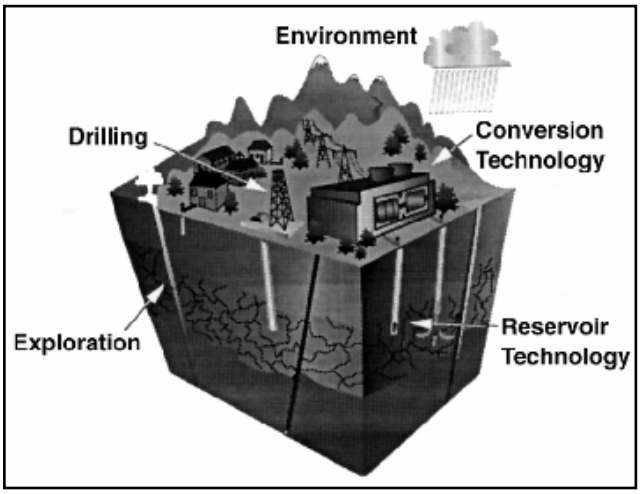
Geothermal Energy

Technology Description

Geothermal energy is thermal energy from within the Earth. Hot water and steam are used to produce electricity or applied directly for space heating and industrial processes. There is potential to use geothermal energy to recover minerals and metals present in the geothermal brine.



System Concepts

- Geophysical, geochemical, and geological exploration locate permeable hot reservoirs to drill.
- Wells are drilled into the reservoirs.
- Well fields and distribution systems allow the hot geothermal fluids to move to the point of use, and are injected back to the earth.
- Steam turbines using natural steam or hot water flashed to steam, and binary turbines produce mechanical power that is converted to electricity.
- Direct applications utilize the thermal energy directly, for heating, without conversion to another form of energy.

Representative Technologies

- Dry-steam plants, which use geothermal steam to spin turbines.
- Flash-steam plants, which pump deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines.
- Binary-cycle plants, which use moderately hot geothermal water to heat a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash to vapor, which then drives the turbines.
- Exploration technologies for the identification of fractures and geothermal reservoirs; drilling to access the resource; geoscience and reservoir testing and modeling to optimize production and predict useful reservoir lifetime.

Technology Applications

- Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that drive turbines and electricity generators. Because of economies of scale, geothermal power plants supply power directly to the grid, typically operating as baseload plants.
- Another use is direct applications to use the heat from geothermal fluids without conversion to electricity. In the United States, most geothermal reservoirs are located in the western states, Alaska, and Hawaii; but some eastern states have geothermal resources that are used for direct applications. Hot water near the Earth's surface can be piped directly into facilities and used to heat buildings, grow plants in greenhouses, dehydrate onions and garlic, heat water for fish farming, and pasteurize milk. Some cities pipe the hot water under roads and sidewalks to melt snow. District heating systems use networks of piped hot water to heat many buildings in a community.
- The recovery of minerals and metals from geothermal brine can add value to geothermal-power projects.

Current Status

- Hydrothermal reservoirs provide the heat for about 2,400 MW of operating generating capacity in the United States at 18 resource sites. Another 700 MW of capacity at The Geysers was shut down.
- Three types of power plants are operating today: dry steam, flash steam, and binary.
- Worldwide installed capacity stands at about 8,000 MW.
- The United States has a resource base capable of supplying heat for 40 GW of electrical capacity at costs competitive with conventional systems. With improved technology, this resource base could expand to 100 GW of electricity at 3 to 5¢/kWh.
- Hydrothermal reservoirs are being used to produce electricity with an online availability of 97%; advanced energy conversion technologies are being implemented to improve plant thermal efficiency.
- Direct applications capacity is about 600 MW_t in the United States.
- Direct-use applications are successful, but require colocation of a quality heat source and need.
- More than 20 states use the direct use of geothermal energy, including Georgia and New York. About 300 MW of geothermal energy is being developed in California, Nevada, and Idaho.
- Current leading geothermal technology companies include the following:
  - Calpine Corporation
  - Caithness Energy
  - Cal Energy Company (a subsidiary of Mid American Energy Holding Company)
  - Ormat International, Inc.

Technology History

- The use of geothermal energy as a source of hot water for spas dates back thousands of years.
- In 1892, the world's first district heating system was built in Boise, Idaho, as water was piped from hot springs to town buildings. Within a few years, the system was serving 200 homes and 40 downtown businesses. Today, the Boise district heating system continues to flourish. Although no one imitated this system for nearly 70 years, there are now 17 district heating systems in the United States and dozens more around the world.
- The United States' first geothermal power plant went into operation in 1922 at The Geysers in California. The plant was 250 kW, but fell into disuse.
- In 1960, the country's first large-scale geothermal electricity-generating plant began operation. Pacific Gas and Electric operated the plant, located at The Geysers. The resource at The Geysers is dry steam. The first turbine produces 11 megawatts (MW) of net power and operated successfully for more than 30 years.
- In 1979, the first electrical development of a water-dominated geothermal resource occurred at the East Mesa field in the Imperial Valley in California.
- In 1980, UNOCAL built the country's first flash plant, generating 10 MW at Brawley, California.
- In 1981, with a supporting loan from DOE, Ormat International Inc. successfully demonstrated binary technology in the Imperial Valley of California. This project established the technical feasibility of larger-scale commercial binary power plants. The project was so successful that Ormat repaid the loan within a year.
- By the mid 1980s, electricity was being generated by geothermal power in four western states: California, Hawaii, Utah, and Nevada.
- In the 1990s, the U.S. geothermal industry focused its attention on building power plants overseas, with major projects in Indonesia and the Philippines.
- In 1997, a pipeline began delivering treated municipal wastewater and lake water to The Geysers steamfield in California, increasing the operating capacity by 70 MW.
- In 2000, DOE initiated its GeoPowering the West program to encourage development of geothermal resources in the western United States by reducing nontechnical barriers.
- The DOE Geothermal Program sponsored research that won two R&D awards in 2003, advancing this renewable energy.

Technology Future

The levelized cost of electricity (in constant 1997$/kWh) for the two major future geothermal energy configurations are projected to be:

	2000	2010	2020
Hydrothermal Flash	3.0	2.4	2.1
Hydrothermal Binary	3.6	2.9	2.7

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997.

- New approaches to utilization will be developed, which increase the domestic resource base by a factor of 10.
- Improved methodologies will be developed for predicting reservoir performance and lifetime.
- Advances will be made in finding and characterizing underground permeability and developing low-cost, innovative drilling technologies.
- Further R&D will reduce capital and operating costs and improve the efficiency of geothermal conversion systems.
- Heat recovery methods will be developed that allow the use of geothermal areas that are deeper, less permeable, or dryer than those currently considered as resources.
- Production will continue at existing geothermal plants, totaling 2.2GW. Ten gigawatts of energy may be sourced from geothermal power by 2015, providing sufficient heat and electricity for 7 million homes. By 2020, 20 GW of installed capacity from hydrothermal plants and 20 GW from enhanced geothermal systems may exist. One hundred gigawatts of future construction potential exists for this sector. Direct heat will replace existing systems in 19 western states' markets.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term*. DOE/PI-0002. November 2003.

Geothermal

Market Data

Cumulative Installed Capacity

Source: U.S. electricity data from EIA, *Annual Energy Review 2003*, DOE/EIA-0384(2003) (Washington, D.C., September 2004), Table 8.11a; world totals from *Renewable Energy World*/July-August 2000, page 123, Table 1; 1998 world totals from *UNDP World Energy Assessment 2000*, Tables 7.20 and 7.25; 1997 world electricity and U.S. and world direct-use heat data from Stefansson and Fridleifsson 1998, "Geothermal Energy: European and World-wide Perspective."

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Electricity (MW_e)												
U.S.	909	1,580	2,666	2,968	2,893	2,893	2,893	2,846	2,793	2,216	2,252	2,252
Rest of World	1,191	3,184	3,166	3,829		5,128	5,346		5,181			
World Total	2,100	4,764	5,832	6,797		8,021	8,239		7,974			
Direct-Use Heat (MW_{th})												
U.S.						1,905						
Rest of World						7,799						
World Total	1,950	7,072	8,064	8,664		9,704	11,000		17,175			

Cumulative Installed Capacity

Source: International Geothermal Association, http://iga.igg.cnr.it/index.php

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Electricity (MW_e)												
U.S.			2,775	2,817					2,228			2,020
Rest of World			3,057	4,016					5,746			6,382
World Total			5,832	6,833					7,974			8,402
Direct-Use Heat (MW_{th})												
U.S.				1,874					3,766			4,350
Rest of World				6,730					11,379			
World Total				8,604					15,145			

Annual Installed Electric Capacity (MW_e)

Source: Renewable Energy Project Information System (REPiS), Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003*
U.S.	251.0	352.9	48.6		36.0				59.9			

Cumulative Installed Electric Capacity (MW_e)

Source: Renewable Energy Project Information System (REPiS), Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003*
U.S.	802	1,698	2,540	2,684	2,720	2,720	2,720	2,720	2,779	2,779	2,779	2,779

* 2003 data not complete as REPiS database is updated through 2002.

Installed Capacity and Power Generation/Energy Production from Installed Capacity

Source: Lund and Freeston, *World-Wide Direct Uses of Geothermal Energy 2000*, Lund and Boyd, Geothermal Direct-Use in the United States Update: 1995-1999, J. Lund, *World Status of Geothermal Energy Use Overview 1995-1999* http://www.geothermie.de/europaundweltweit/Lund/wsoge_index.htm, Sifford and Blommquist, *Geothermal Electric Power Production in the United States: A Survey and Update for 1995-1999*, and G. Huttrer, *The Status of World Geothermal Power Generation 1995-2000.* Proceedings of the World Geothermal Congress 2000 http://geothermal.stanford.edu/wgc2000/SessionList.htm, Kyushu-Tohoku, Japan, May 28-June10, 2000.

Cumulative Installed Capacity

	1980	1985	1990	1995	1996	1997	1998	1999	2000
Electricity (MW_e)									
U.S.				2,369	2,343	2,314	2,284	2,293	2,228
Rest of World				4,464					5,746
World Total	3,887	4,764	5,832	6,833					7,974
Direct-Use Heat* (MW_{th})									
U.S.									4,200
Rest of World									12,975
World Total	1,950	7,072	8,064	8,664				16,209	17,175

Annual Generation/Energy Production from Cumulative Installed Capacity

	1980	1985	1990	1995	1996	1997	1998	1999	2000
Electricity (Billion kWh_e)									
U.S.				14.4	15.1	14.6	14.7	15.0	15.5

Rest of World					33.8
World Total					49.3
Direct-Use Heat* (TJ)					
U.S.		13,890		20,302	21,700
Rest of World		98,551		141,707	
World Total	86,249	112,441		162,009	185,139

* Direct-use heat includes geothermal heat pumps as well as traditional uses. Geothermal heat pumps account for 1854 MW_{th} (14,617 TJ) in 1995 and 6849 MW_{th} (23,214 TJ) in 1999 of the world totals and 3600 MW_{th} (8,800 TJ) in 2000 of the U.S. total. Conversion of GWh to TJ is done at 1TJ = 0.2778 GWh.

Annual Generation from Cumulative Installed Capacity

Source: U.S. electricity data from EIA, *Annual Energy Review 2003*, DOE/EIA-0384(2003) (Washington, D.C., September 2004), Table 8.2a; world electricity totals from *Renewable Energy World*/July-August 2000, page 126, Table 2; 1997 world electricity and U.S. and world direct-use heat data from Stefansson and Fridleifsson 1998, "Geothermal Energy: European and World-wide Perspective." 1998 world totals from UNDP World Energy Assessment 2000, Table 7.25; 1995, 2000, and 2003 direct-use heat and 1999 electricity world total from International Geothermal Association, http://iga.igg.cnr.it/index.php.

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Electricity (Billion kWh_e)												
U.S.	5.1	9.3	15.4	13.4	14.3	14.7	14.8	14.8	14.1	13.7	14.5	13.1
Rest of World	8.9	7.7	3.6	6.6		29.0	31.2		35.2			
World Total	14	17	19	20		43.8	46	49	49.3			
Direct-Use Heat (billion kWhth)												
U.S.				3.9		4.0			5.6			6.2
Rest of World				27.4		31.1			47.3			
World Total				31.2		35.1	40		53.0			

Annual Geothermal Energy Consumption for Electric Generation (Trillion Btu)

Source: EIA, *Annual Energy Review 2003*, DOE/EIA-0384(2003) (Washington, D.C., September 2004), Table 8.4a.

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.	110	198	326	280	300	309	311	312	296	289	305	276
Rest of World												
World Total												

Annual U.S. Geothermal Heat Pump Shipments, by type (units)

Source: EIA, *Renewable Energy Annual 2003*, DOE/EIA-0603(2003) (Washington, D.C., December 2004), Table 37.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001*	2002	2003
ARI-320				4,696	4,697	7,772	10,510	7,910	7,808	N/A	6,445	10,306
ARI-325/330				26,800	25,697	28,335	26,042	31,631	26,219	N/A	26,802	25,211
Other non-ARI Rated				838	991	1,327	1,714	2,138	1,554	N/A	3,892	922
Totals				32,334	31,385	37,434	38,266	41,679	35,581	N/A	37,139	36,439

* No survey was conducted for 2001.

Capacity of U.S. Heat Pump Shipments (Rated Tons)

Source: EIA, *Renewable Energy Annual 2003*, DOE/EIA-0603(2003) (Washington, D.C., December 2004), Table 38.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	20012	2002	2003
ARI-320				13,120	15,060	24,708	35,776	27,970	26,469	N/A	16,756	29,238
ARI-325/330				113,925	92,819	110,186	98,912	153,947	130,132	N/A	96,541	89,731
Other non-ARI Rated				3,935	5,091	6,662	6,758	9,735	7,590	N/A	12,000	5,469
Totals				130,980	112,970	141,556	141,446	191,652	164,191	N/A	125,297	124,438

1 One Rated Ton of Capacity equals 12,000 Btu's.

2 No survey was conducted for 2001.

Annual U.S. Geothermal Heat Pump Shipments by Customer Type and Model Type (units)

Source: EIA, *Renewable Energy Annual 2003*, DOE/EIA-0603(2003) (Washington, D.C., December 2004), Table 40, REA 2002 Table 40, REA 2001 Table 40, REA 2000 Table 38, REA 1999 Table 38, and REA 1998 Table 40.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001*	2002	2003
Exporter					2,276	226	109	6,172	784	N/A	1,165	945
Wholesale Distributor					21,444	29,181	14,377	9,193	9,804	N/A	20,888	16,167
Retail Distributor					8,336	829	3,222	2,555	2,272	N/A	552	1,145
Installer					18,762	25,302	18,429	24,917	20,491	N/A	10,999	10,784
End-User					689	657	994	66	63	N/A	207	1,103
Others					13	1,727	1,135	6,259	2,167	N/A	3,328	6,295
Total					51,520	57,922	38,266	49,162	35,581	N/A	37,139	36,439

Annual U.S. Geothermal Heat Pump Shipments by Export & Census Region (units)

Source: EIA, *Renewable Energy Annual 2003*, DOE/EIA-0603(2003) (Washington, D.C., December 2004), Table 39, REA 2002 Table 39, REA 2001 Table 39, REA 2000 Table 37, REA 1999 Table 37, and REA 1998 Table 39.

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**
Export					4,090	2,427	481	6,303	1,220	N/A	3,271	2,764
Midwest					11,874	13,402	12,240	13,112	10,749	N/A	12,982	12,042
Northeast					6,417	9,280	5,403	6,044	4,138	N/A	3,903	5,924
South					25,302	26,788	16,195	20,935	17,403	N/A	13,660	12,543
West					3,837	6,025	3,947	2,768	2,071	N/A	3,323	3,166
Total					51,520	57,922	38,266	49,162	35,581	N/A	37,139	36,439

Technology Performance

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997 (this document is currently being updated by DOE and the values most likely will change).

Efficiency		**1980**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Capacity Factor (%)	Flashed Steam			89	92	93	95	96	96
	Binary			89	92	93	95	96	96
	Hot Dry Rock			80	81	82	83	84	85
Cost		**1980**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Capital Cost ($/kW)	Flashed Steam			1,444	1,372	1,250	1,194	1,147	1,100
	Binary			2,112	1,994	1,875	1,754	1,696	1,637
	Hot Dry Rock			5,519	5,176	4,756	4,312	3,794	3,276
Fixed O&M ($/kW-yr)	Flashed Steam			96.4	87.1	74.8	66.3	62.25	58.2
	Binary			87.4	78.5	66.8	59.5	55.95	52.4
	Hot Dry Rock			219	207	191	179	171	163